Mapping Land Cover Patterns of Gunma Prefecture, Japan, by Using Remote Sensing

Zhaohui Deng, Yohei Sato, Hua Jia

Department of Biological and Environmental Engineering, Graduate School of Agricultural and Life Sciences, The University of Tokyo,Tokyo, Japan 113-8657

E-mail: z-deng@basic-hq.co.jp

E-mail: aysato@mail.ecc.u-tokyo.ac.jp

ABSTRACT

A set of land-cover pattern maps for the Gunma Prefecture was produced to help understand and assess the ecological implications of regional spatial patterns. Covering a total area of approximately 6,360 square kilometers, about 77 percent of this area can be regarded as "vegetation cover". The land cover map was derived from the supervised classification process with the combined use of TM, SPOT and aerial images. Six aggregated classes are forest, agriculture, grass, bare land, urban, water, with class proportion of 73.91%, 8.57%, 3.77%, 3.08%, 10.22%, 0.45% respectively. A series of spatial filters to the land-cover maps is applied to derive new maps of pattern indicators. Five pattern indices were mapped: forest connectivity, forest area density, land-cover connectivity, land-cover diversity, and landscape pattern types. Mainly according to the topographical conditions in the direction of from east to west, Gunma prefecture was divided into three subregions: urban, suburban and mountainous area. Patches-patch size method was utilized to determinate the pattern scale, i.e., kernel size, and grain size. Results show that grain size of 0.0147km^{2,} and kernel size of 16*16,16*16,12*12 pixel for urban, suburban and mountainous regions, respectively, were suitable parameters for pattern mapping.

KEY WORDS: Land cover, pattern map, grain, kernel size, patches-patch sizes, remote sensing

1. INTRODUCTION

Land cover and its spatial patterns are key ingredients in ecological studies considering large regions and the impacts of human activities (Forman et al., 1986; Turner et al., 1990). The proportions of different land-cover types show the importance in explaining the spatial variation of other environmental parameters (O'Neill et al., 1997). Although patterns are sometimes easy to see on a land-cover map, further processing of land-cover data is needed to quantify those patterns. In other cases, further processing is needed to extract pattern information that is not visually apparent (Ritters et al., 2000; Lynch and Whigham 1984; Krummel et al., 1987; Hunsaker et al., 1995; Vogelmann 1998; Franklin et al., 1987).

A set of land-cover pattern maps for the Gunma Prefecture is to be produced to help us to understand and assess the ecological implications of regional spatial patterns. The land-cover pattern data are suggested for several purposes, depending on the scale of inquiry. First, they may provide contextual information for studies involving a set of field sites, and could be used as independent variables or attributes for stratification. Second, they can be used as indicators in landscape-scale assessments of ecological conditions, and can be summarized by assessment units such as watersheds, ecoregions, or counties. Third, they may be useful as dependent variables in even coarser-scale biogeographic models, or in socio-economic models of human land use and development (Ritters et al., 2000).

Five indices are to be adopted to map Gunma Prefecture, which is characterized by large portion of vegetation cover. Grain size and pattern scale, i.e., kernel size are two key issues in pattern mapping. O'Neill examined the scale problems involved in reporting landscape pattern for a large, heterogeneous region with the case study of Southeastern United States, and found the frequency distributions of landscape indices illustrate problems associated with the grain or resolution of the data. O'Neill concluded that grain should be 2 to 5 times smaller than the spatial features of interest, and to avoid bias in calculating the landscape indices "sample area" must be 2 to 5 times larger than landscape patches (1996). The patches-patch size method proposed by O'Neill (1996) is to be utilized to analyze patch frequency and cover type proportion, thus deducing the specific grain size and pattern scale. Remotely sensed data involving TM, SPOT and aerial images, and supervised classification result in land cover data recorded in digital format. VC++ programming calculate the land pattern map with PC environment.

2. MATERIALS AND METHODS

2.1 Location

Gunma Prefecture covers a total area of approximately 6,360 square kilometers (636,000 hectares). About 77 percent of this area can be regarded as “vegetation cover”. There are many different types of “vegetation cover” in Gunma Prefecture, including forest, parks, reserves, grassland, and other natural areas.

Analysis of satellite imagery allows maps of land cover to be prepared. In addition, the use of satellite imagery obtained on different dates allows the mapping of changes in land cover over time.

Landsat Thematic Mapper (TM) satellite imagery is ideal for mapping large areas at relatively small scales (e.g. 1:100,000 or smaller). However, large-scale mapping requires the use of other data sources, such as SPOT satellite imagery, or aerial photography.

2.2 Data Sources

Data sources include:

(1) Landsat-5 TM .The following 1996 Landsat Thematic Mapper (TM) satellite data were used in the analysis work (table 1):

Table 1: Used landsat-5 imagery

Path/Row	Landsat-5 TM Overpass Date
108-034	October 27, 1996
108-035	October 27, 1996

(2) Ancillary Data. Aerial Photography (partial coverage of Gunma Prefecture) and 1:25,000 topographic maps of Gunma Prefecture (table 2).

Table 2:Ancillary data

Type	Photo Acquisition Date
B &W	May 09 – 23, 1994
B&W	October 14/15, 1994
Color	November 10, 1994
Color	May 27, 1995
B&W	May 25, 1996

(3) Hard Copy Images. SPOT Multispectral image “quick look” print for visual interpretation. The original image was acquired on October 3, 1994 (SPOT K328 J276). This image covered the northwestern part of Gunma Prefecture, and was cloud-free in the region that was obscured by clouds in the 1996 Landsat TM imagery.

2.3 Data Processing

The step of data processing includes:

(1) Georeferencing. The coordinate system used for the was UTM Zone 54 North, the datum was Tokyo, and the spheroid was Bessel. A total of 106 ground control points were utilized, and the overall residual of mean square error was 0.4789 pixels (approximately 14 meters, which corresponds to about 0.5 mm on a 1:25,000 topographic map).

(2) Rectification and Mosaicing. The two rectified images were assembled together to create a single image. No contrast matching was required, because both images were obtained from Path 108 on the

same day. Therefore the image brightness parameters for the two scenes were almost identical.

（3）Identification of Land Cover. Sample sites with a known land cover, as determined by photo interpretation and field reconnaissance work, were identified in the aerial initial photographs. These sites were used as "training sets" for an automated supervised classification. Theoretically, using the concept of spectral signatures allows each pixel in a digital multispectral image to be classified as belonging to a particular land cover class, based on its relative brightness in each spectral band (Richards, 1986). However, pixels in satellite images generally represent mixtures of various land cover components such as vegetation, soil, water, etc. It is unusual for a pixel to represent a pure land cover class in a satellite image.

Figure 1 shows a 2-dimensional idealized representation of spectral classes for water, vegetation and

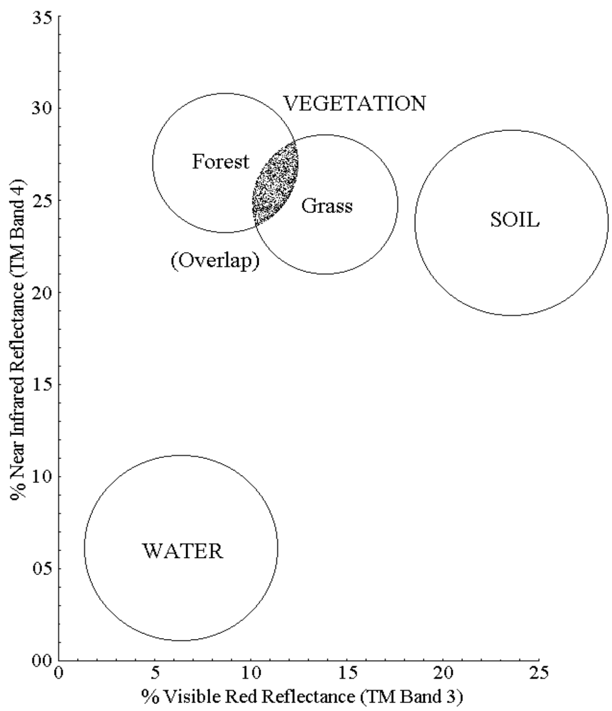

Figure 1. Idealized 2-Dimensional Spectral Plot for Water, Vegetation and Soil

A total of 236 spectral signatures, which were represented for 236 kinds of landcovers were originally identified in images. A well-documented and practicable procedure, maximum likelihood classifier in ERDAS Imagine was employed to make classification.

(4) Aggregation of Land Cover Classes. Table 3 shows which original land cover classes were aggregated to form the new land cover classes.

Table 3: Original class and aggregated class

Original Class	Aggregated Class
Grass, shrubs, and sparse vegetation	Grass
Marshland	
Pine forest	Forest
Deciduous forest with green leaves	
Deciduous forest with autumn color leaves	
Yellow stubble and dry grass	Agriculture
Seasonal crops (e.g. market gardens, orchar etc.)	
Bare rock with very sparse vegetation	Bare Land
Bare soil and land development	
Urban and infrastructure	Other

Figure 2 shows the indexed land cover map.

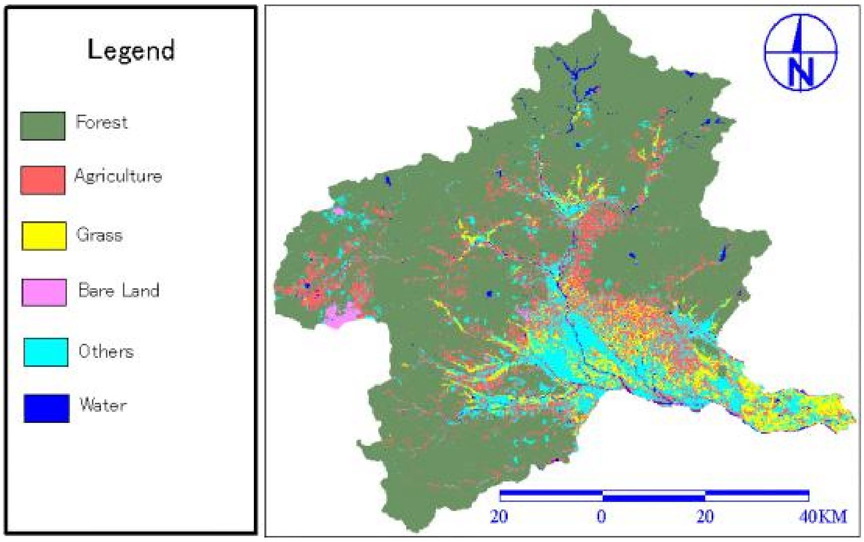

Figure 2: Land cover map of Gunma Prefecture

2.4 INDICES OF LAND COVER PATTERN

A series of spatial filters were applied to the land-cover maps, to derive new maps of pattern indicators. A convolution filter places a "window" (support region, or kernel) on each pixel of land cover, calculates the pattern index within the window, and puts the result on a new map at the same location. Thus, the value of a pixel in one of the new maps represents an index of land-cover pattern for the surrounding window in the original land-cover map. Five pattern indices are mapped: forest connectivity, forest area density, land-cover connectivity, land-cover diversity, and landscape pattern types, which are exactly follow what Ritters et al proposed (2000).

Consider a window placed somewhere on a land-cover map. Let t be the number of land-cover types, after any aggregation of land-cover types that is particular to a given pattern index. Let Pi (i = 1 to t) be the proportion of non-missing pixels in the window of the ith type. The Pi values are used in four of the five indices as follows:

1) Forest area density, an index of forest amount, is the proportion of forest in the window, as determined from a map with all forest types aggregated into one. The index is continuous over [0,1].

2) Landscape pattern types (LPT's) provide geographic strata for identifying differences in landscape characteristics (e.g., forest patch size, amount of edge). They are motivated by the prevailing tendency for land cover to be spatially autocorrelated. The proportions are compared to each other, and to the critical values of 0.001 and 1.0, to yield categories indicating general land use themes. Landscapes dominated by one land cover appear to be qualitatively different from landscapes with a more even distribution of land-cover types.

3) Land-cover diversity is analogous to Simpson's (1949) index, $1 - \sum_i P_i^2$, where Pi are the land-cover type proportions. The index is continuous over [0,1] and higher values are taken to indicate greater diversity. Simpson's index is easy to visualize and its properties are understood by many ecologists. Compared to most other diversity indices, Simpson's index is relatively more sensitive to changes in abundant land-cover types and less sensitive to changes in rare types (and thus, to classification errors in the land-cover maps).

The other two indices are texture measures derived from an attribute adjacency table (Musick and Grover, 1991), in which F_{ij} (i,j = 1 to t) is the frequency of adjacent pixel pairs with land-cover types {i,j}. When forming the attribute adjacency table, adjacency is evaluated in the four cardinal directions, each edge is counted once, the order of pixels in pairs is not preserved, and pairs involving a missing pixel are not included. Define $G_i = \sum_j F_{ij}$ and $W_i = F_{ii} / \sum_{I,j} F_{ij}$ for the ith land-cover type.

4) Forest connectivity was measured by the conditional probability that two adjacent pixels in a given window are forest, given that the first is forest. The index is calculated as F_{ii} / G_i where i refers to all forest types aggregated into one. It is continuous over [0,1]. The index is of interest because of

concern regarding forest "fragmentation," which can be estimated as one minus the connectivity index.

5) Land-cover connectivity was measured as $\sum_i W_i$, i.e., as the overall probability that adjacent pixels had the same land-cover type. The index is continuous over [0,1] and is available for a window size. Larger connectivity values indicate relatively less overall fragmentation in the window.

2.5 GRAIN AND KERNEL SIZE

For purposes of monitoring and assessing changes across medium and large region, there is a need to consider the regional scale. A region is an area of similar vegetation, geology, and historic land use such that principles of landscape ecology established anywhere within the region can be reasonably expected to extrapolate across the region (Omernik 1987). The landscape unit will depend on the question being asked. For questions of forest biodiversity, the logical unit might be a forest patch. For questions of water quality assessment, the unit might be a watershed. In this paper, Gunma prefecture is divided into 3 sub-regions according to the combined rule of DEM topography and forest patch size(Figure 3)

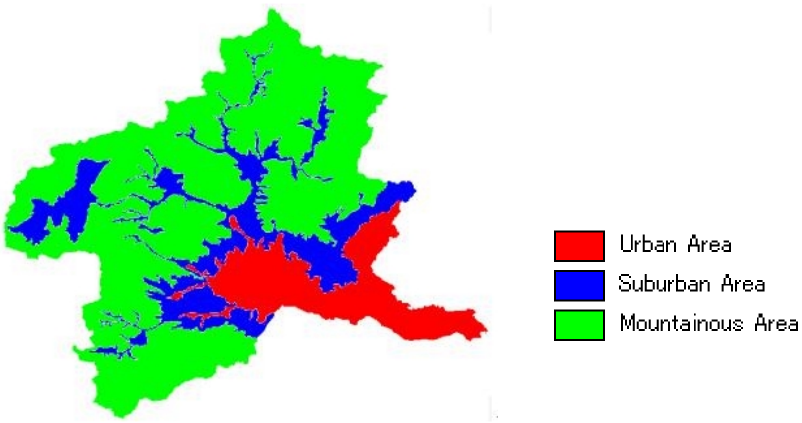

Figure 3:Division of Gunma Prefecture

The original resolution of landsat TM image is 30*30m(0.09ha), which results in huge image size over regional scale. What is the suitable grain size? For Gunma Prefecture, a generalized image with 941pixel*1119 pixel and a grain size of 1.47ha was created. A patch analysis method was proposed to certify its reasonableness.

Now consider the frequency distribution of land cover patch sizes in Gunma Prefecture. With a grain size of 1.47ha, the patches with area less than 1.47ha are lost. Values between 0 and 1.47ha are lumped as 2.0ha. To examine the detailed land cover patch frequency, 15 classes have been built with the first class area ranging between 0 and 0.5ha and the last class area larger than 276,894ha. The first class has too many member. Figure 4 shows the frequency distribution of landcover patch size in Gunma prefecture. The graph shows the area , summed over five land covers except bareland. 15 classes have been built with the first class area ranging between 0 and 0.5ha. It could be observed that the landscape distribution lies to the right of center, i.e., the patches tend to be small.

With only the graph of patches frequency is insufficient to make certain the constitution of small patches, the graph of patch-percentage is well suited to demonstrate the area portion over total area. Figure 5 shows the area proportion of each patch class over the total area. The mode of distribution lies far to the left of center, i.e., the small patches constitute small portion although they top in patch numbers.

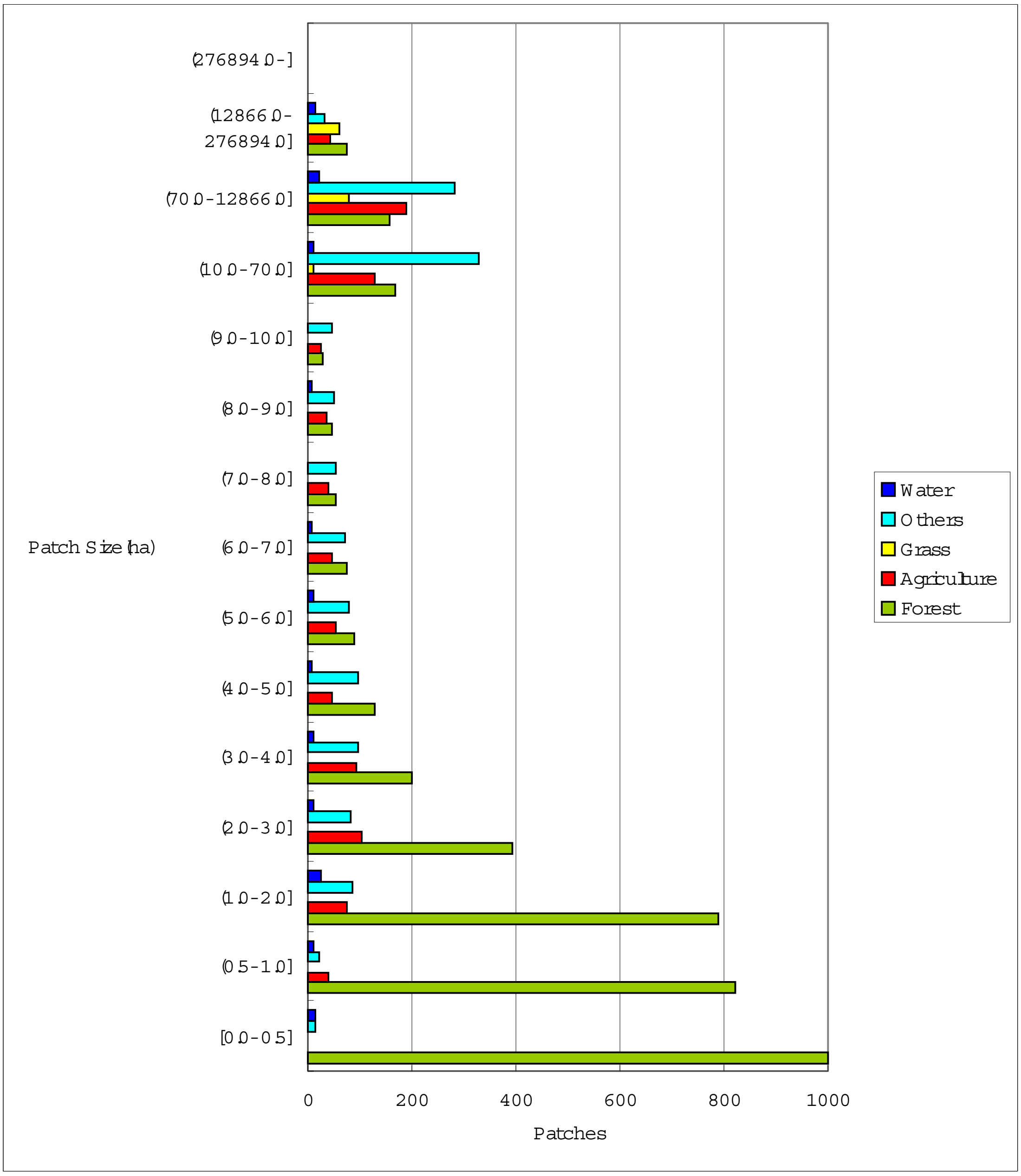

Figure 4: Frequency distribution of land cover patches in Gunma Prefecture. Values are the total area occupied by patches of a given size, summed over five land cover types. Patch size takes the unit of hectare, while patches is the number of patches. The mode of distribution lies to the right of center and it shows the characteristic peak at the small patch size.

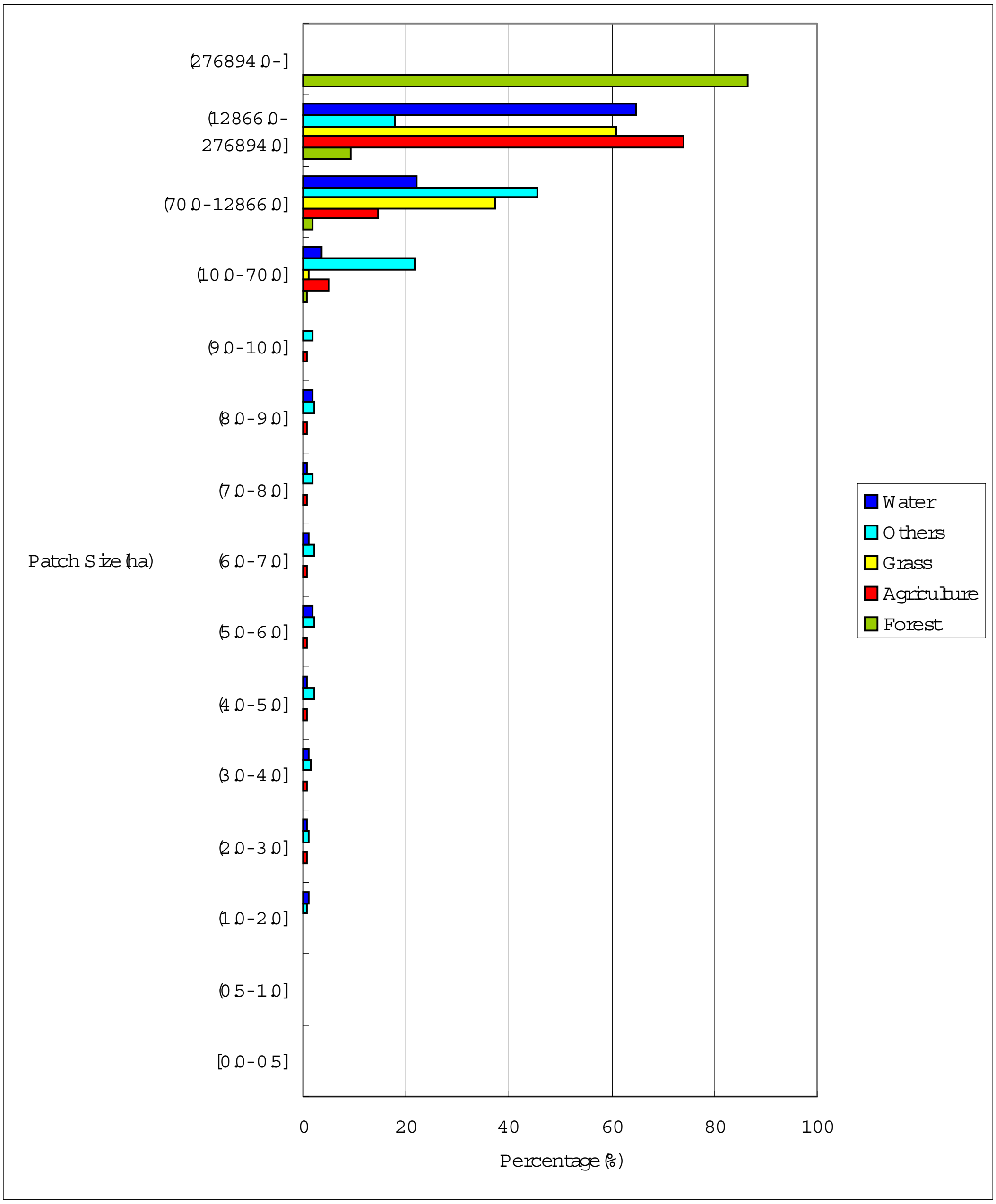

Figure 5: Frequency distribution of land cover patch size with respect to percentage in Gunma Prefecture. The mode of distribution lies to the left of center and it shows that patches with small area only take up small propotion in the total area.

Taking into consideration of both figure 4 and figure 5, it could be concluded that 1) Gunma landscape is characterized by the mixture of a large number of small patches with some big patches, which suggests that pixel sampling should have a good care for small patches. 2) The grain size of 1.47ha could keep the original landscape characteristic without the loss of patch distinguishability.

Using a coarse-grained database biases the estimation of small patch size for the loss detailed information. There is no a theoretically proved method to define a good resolution for reference. O'Neill et al., (1996) suggested an arbitrary, but practical, rule from their experience: for indices that are sensitive to small landscape features, the grain of the data should be 2 to 5 times smaller than the feature of interest.

Gunma area is 6360km2, while in raster image, the number of pixels is 431658, which means every pixel covers an area of 0.0147 km^2. The number of pixels in each class is 332344, 61440, 24872, 2839, 5374 and 4798, for forest, agriculture, grass, bare land, urban and water, respectively. In urban area, the average area of all patches is 0.46 km^2. 1.5 km^2 is selected as the area of sample window such that window size is 12*12; in buffer area, the average area of patches is 0.89 km^2. 4 km is selected as the sample area such that window size is 16*16 pixel; in mountainous area forest covers this area 5373km^2. 16*16 pixel is selected.

3. RESULTS

Figures 6 to 10 illustrate the five pattern indices derived in Gunma prefecture. The landscape pattern types for the area are shown in Figure 6. Not all of the 6 possible landscape pattern types appear here because there is little water and its scattering distribution. An apparent gradient from concentration s of urban land use to concentrations of forestland use could be observed. Along the gradient, the LPT map identifies regions of decreasing urban land use. Figure 7 tells the forest area density index distribution, which has the similar gradient like figure 6. The gradient indicates regions of increasing forestland.

Figure 8 illustrates the land cover diversity pattern in Gunma Prefecture. Obviously, suburban region has wide variety of land cover than urban and mountainous region as suburban region severing as a transition area between urban and forest area.

Figure 9 and figure 10 illustrated the relationship between forest connectivity index and land cover. Forestland cover dominates the mountainous area but is less abundant in the suburban area and scare in urban area.

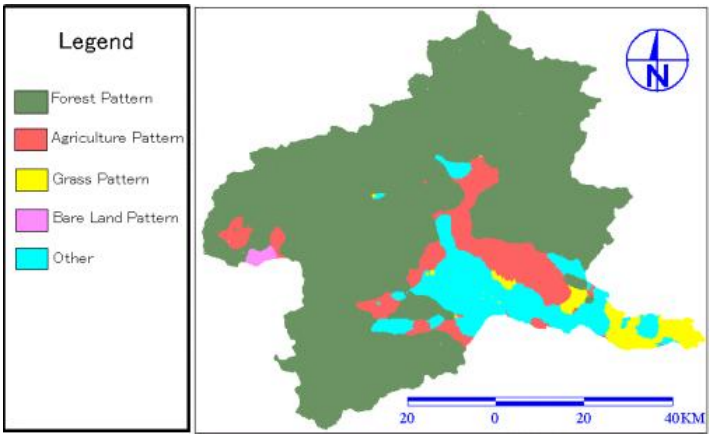

Figure 6:Landscape Pattern Type. Water disappear here due to little area and its scattering distribution

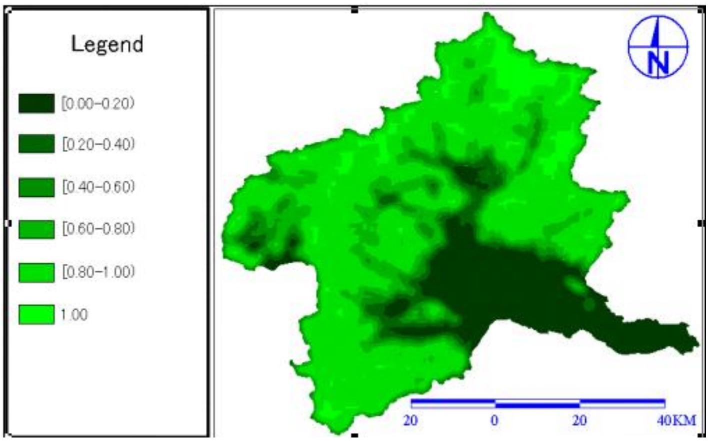

Figure 7: Forest Area Density Pattern

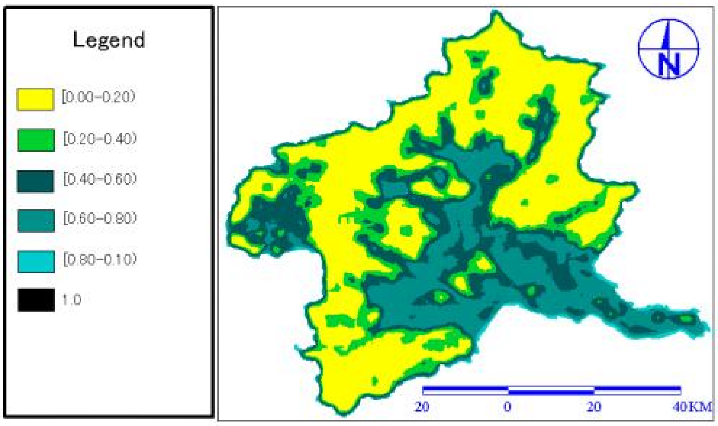

Figure 8:Land Cover Diversity Pattern

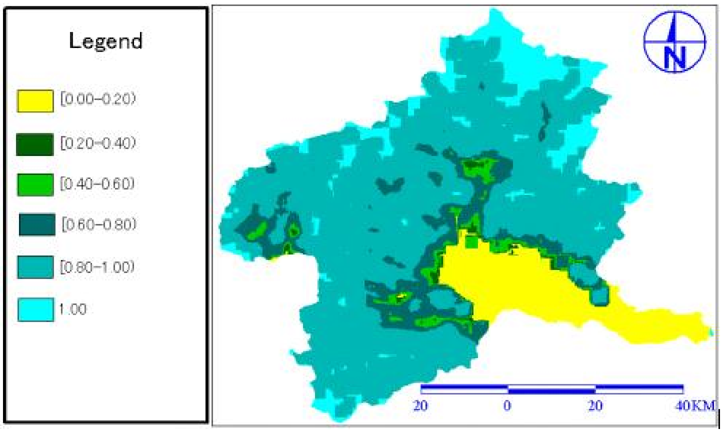

Figure 9:Forest Connectivity Pattern

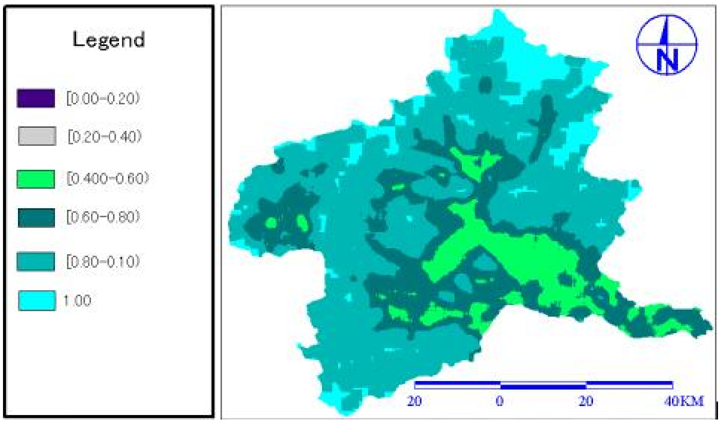

Figure 10: Land Cover Connectivity

4. CONCLUSION

Mapping land cover patterns involves a series of procedures, including classification of remotely sensed data, patch map making, analysis of the frequency of patches and proportion in total area to make reasonable the critical threshold to avoid the bias of landscape estimation, evaluation of grain size, defining filter window size, selection of indices and computation conducting. With the proposed procedures, regional land cover data and the derived pattern maps are currently available for Gunma Prefecture of Japan.

Pattern maps are useful because they quantify biologically relevant information that is not necessarily evident from land cover map. Yet much remains to be learned about how to measure pattern in meaningful ways. The pattern information may become more reliable for characterizing ecological conditions over large regions. Spatial scale is also important. Not only because different ecological patterns emerge at different scales of investigation, but also because all measures of pattern are more or less sensitive to it. The method used in this paper to determinate pattern scale is out of expert's experience with the help of frequency distribution of land cover patches, which was demonstrated to be practicable. Our choices of indices are based on experiences. We expect that the pattern data presented here will be useful for testing hypotheses related to land cover/land use change at regional scales or other possibilities.

5. ACKNOWLEDGEMENTS

Basic Engineering Co. and GeNet Co. are greatly acknowledged for their provision of remotely sensed image, georeferenced data, and field reconnaissance. Most of the classification result is from one government engineering project titled Gunma Prefecture Pilot Project, undertaken by Basic Engineering Co.

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